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Aerosol-Cloud-Drizzle-Turbulence Interactions in Boundary Layer Clouds

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LONG-TERM GOALS

The long term-goal of this project is to provide an improved description and understanding of the effects of aerosol-cloud interactions and drizzle and entrainment processes in boundary layer clouds for the purpose of developing, improving, and evaluating cloud and boundary layer representations in LES, mesoscale and large-scale forecast models.

OBJECTIVES

The scientific objectives are to: 1) document the structure and characteristics of entrainment circulations in marine stratocumulus and fair-weather-cumuli, 2) characterize the vertical distribution of drizzle and how it relates to cloud and mesoscale circulations; 3) investigate the relative role of cloud thickness, cloud turbulence intensity, and aerosols on drizzle production; 4) study the processing of aerosols by cloud processes; and 5) explore mass, moisture, and aerosol transports across interfacial regions at cloud base and at the capping inversion.

APPROACH

The observations needed for this study are made using NAVY CIRPAS Twin Otter research aircraft and includes the use of an FMCW cloud radar to track drizzle and cloud features while making simultaneous *in situ* measurements of aerosols and cloud characteristics. Further, we plan to make use of the cloud radar with radar chaff to track air motions in and out of the clouds. Cloud seeding techniques demonstrated in an earlier ONR funded study will be extended to study the response of cloud and drizzle processes to the artificial introduction of CCN and giant nuclei under differing aerosol backgrounds. In addition, a set of aerosol and cloud observations in trade wind cumulus clouds using the CIRPAS aircraft with the cloud radar will be developed. The observational components of this study will be made in environments where we expect strong-aerosol-cloud variability. This included observations made during VOCALS (VAMOS Ocean Cloud Atmosphere Land Study) Regional Experiment off the coast of Chile (Oct.-Nov. 2008) where satellite observations indicate strong gradients in cloud properties off the coast. Further we will make use of observations from the South Florida area of fair-weather cumulus clouds (Jan. 2008) where clouds with both marine and continental characteristics are observed. Following these two deployments we plan stratocumulus and fair-weather cumulus seeding and aerosol transport studies in 2010 (Barbados) and 2011 off the coast

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
The long term-goal of this project is to provide an improved description and understanding of the effects of aerosol-cloud interactions and drizzle and entrainment processes in boundary layer clouds for the purpose of developing, improving, and evaluating cloud and boundary layer representations in LES, mesoscale and large-scale forecast models.

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of California and Florida. These studies include the participation of one graduate student and a technician/data analyst. For the VOCALS study we collaborated with Dr. Carl Friehe and Djmal Khief (U. Calif. Irvine) on turbulence observations from the Twin Otter and with Dr. Patrick Chaung (U. Calif. Santa Cruz) on cloud physics measurements. For the later studies, we will consider the possibility of using the towed, instrumented platform being developed by Dr. Friehe. This platform could allow for turbulence observations at two levels across key interfaces at cloud top and cloud base to study entrainment and cloud-subcloud transport processes.

WORK COMPLETED

In Januray-February 2008, the CIPAS Twin Otter was used to study aersosl, cloud, precipitation and turbulence observation in the South Florida area. A total of 15 flights were flown and provided sampling over a wide range of aerosol, cloud and boundary layer conditions. Flights were made over water and over land to provide boundary layer turbulence variations. Substantial boundary layer variations were observed and cloud conditions encountered included nearly solid stratocumulus, shallow non-precipitating cumulus, and shallow precipitating cumulus. Thus a full range of aerosol, cloud, and boundary layer conditions were sampled during the deployment and a rich data set for understaing key physical processes operating in these clouds was obtained. Work is currently in progress to analyze the data that were collected during these aircraft missions and to develop LES casesbased on these observations. During this study 3 University of Miami gaduate students (one funded by this grant) participated in the aircraft observations. Further, undegradaute meterolgy students from UM toured the CIRPAS Twin Otter facility and received instument tutorials as an enhancement to their meterological intrumentation class.

As part of this research project we are using observations from the CIRPAS Twin Otter research aircraft that was deployed for the VAMOS Ocean-Cloud-Atmosphere-Land Study -Regional Experiment (VOCALS-Rex; October to November 2008) over the subtropical southeastern Pacific to investigate physical, cloud, aerosol and chemical processes in this region. The CIRPAS Twin Otter aircraft made 19 research flights off the coast of Northern Chile during VOCALS-REx from Oct. 15 to Nov. 15. Cloud conditions were excellent during this deployment. Operations were coordinated from Iquique Chile. The flight strategy involved operations at a fixed point (20 S; 72 W; reference point alpha) that allowed for a definition of the temporal evolution of boundary layer structures, aerosols, and cloud properties (Fig. 1) in the coastal environment. Each flight included 3 to 4 soundings and near-surface, below-cloud, cloud base, in cloud, cloud top, and above inversion observations along fixed-height legs. This study used the aerosol, cloud, and boundary-layer thermodynamics and turbulence data from those 18 flights to investigate the boundary layer, and aerosol-cloud-drizzle variations in this region.

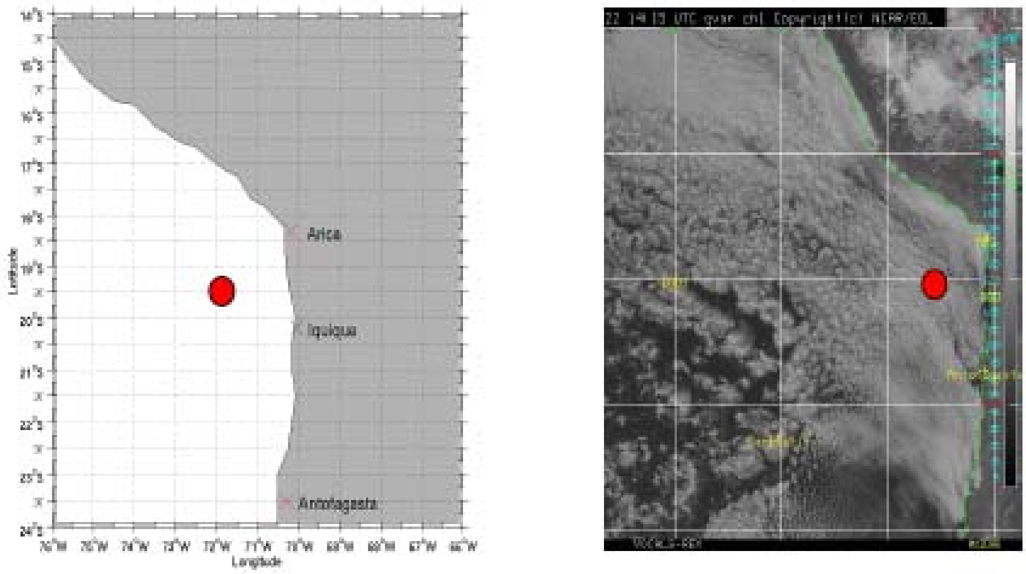

Figure 1 1. Map showing study area for the CIRPAS Twin Otter during VOCALS and visible GOES satellite image showing example of cloud conditions observed at the site.

RESULTS

The observations made during the VOCALS deployment provide a unique characterization of the cloud and aerosol variability in the coastal environment. The evolution of the surface conditions, boundary layer depth, inversion characteristics and the aerosol concentrations in the subcloud layer and above the cloud layer are shown in Fig. 2. The marine atmospheric boundary layer structures observed showed relatively little variability and indicated little influence from meso-scale and large-scale systems. The aerosol and cloud properties demonstrate clear variations over this region during the study with accumulation mode aerosols in the boundary layer varying from 200 – 700 cm^{-3}. Aerosol number concentrations above the boundary layer were substantially smaller than those below (50 - 250 cm^{-3}) except for a two cases where these values were elevated. Cloud droplet concentration varied from 50-400 cm^{-3} over the18 flights. Drizzle water content varied from 10^{-5} to 0.05 g/m3 and 6 flights out of 18 flights have mean drizzle water content larger than 0.0015 g/m3. Since the boundary layer conditions at this fixed point are so steady, the observations provide a unique data set for the evaluation of models operating at a variety of scales—large eddy to large scale.

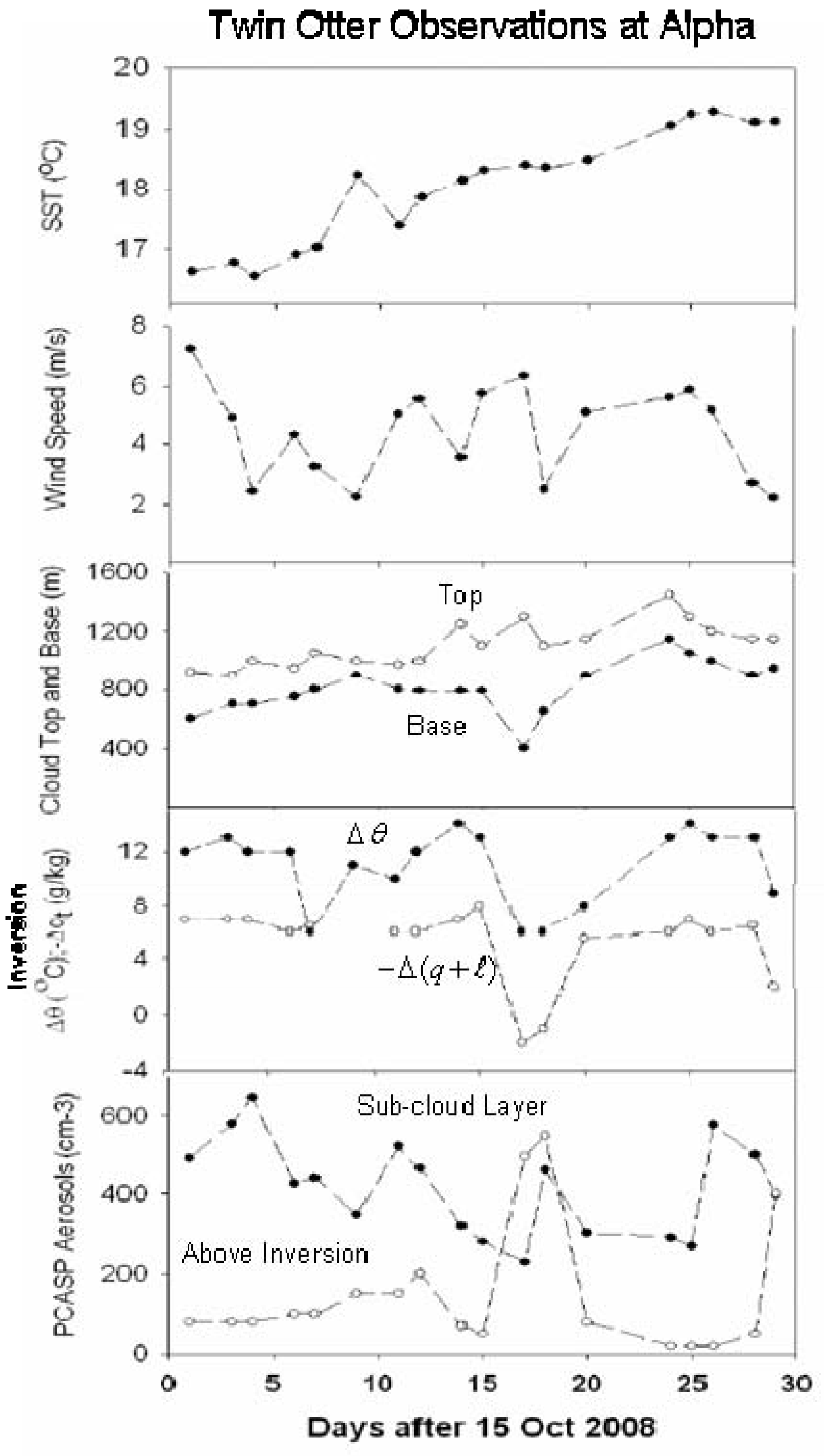

Figure 2. Variations in SST, near surface wind speed, cloud-top and cloud base, inversion jumps in potential temperature and specific humidity, and accumulation mode aerosol concentrations in the subcloud layer and above the inversion observed from the CIRPAS Twin Otter flights during VOCALS.

The boundary layer structures observed on several of the VOCALS flights were remarkably similar, although the observed aerosol concentrations in the boundary layer and the liquid water path of the clouds topping the boundary layer varied considerably. On 8 of the flight days, the boundary layer was well mixed, the clouds sampled were non-precipitating, and conditions at the top and the bottom of the mixed layer were very similar. The inversion heights observed on these flights ranged from 900 to 1300 m, potential jumps across a very sharp capping inversion ranged from 14-17 ^{o}C, and mixing ratio decreases across the inversion ranged from 6-8 g/kg. Calculated boundary layer back trajectories for the 72 hours prior to the observations at 20^{o}N and 72^{o}W remained mostly over coastal ocean areas and indicate that advective effects were generally small during this time. Thus the boundary layer, cloud and aerosol structures sampled on the individual days were likely to be steady and close to equilibrium. Despite the constancy of the thermodynamic structures of the boundary layers studied on these 8 flights, the subcloud CCN concentrations varied substantially and were closely coupled to the cloud droplet concentrations (Fig. 3). CCN in the boundary layer for these cases ranged from and the droplet concentrations ranged from 180 to 580 cm-3, in the relatively thin capping clouds. The liquid water path in these clouds ranged from 22 to 73 gm^{-2} and was positively correlated with the aerosol and cloud droplet concentrations (Fig. 4). Processes that may link the aerosol concentrations and the liquid water path and explain the observed positive correlation is currently being studied, since this correlation is at odds with models studies that indicate entrainment should be enhanced with smaller droplet concentrations.

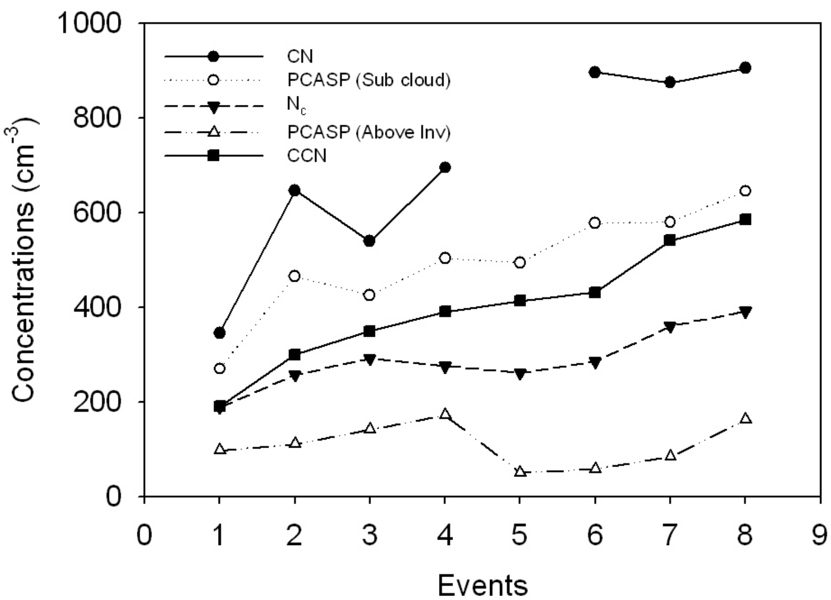

Figure 3. Variations of CN, CCN, and PCASP (accumulation mode aerosols) in the subcloud layer amd Nc (cloud droplet concentrations) for the eight flights described in detail. Events were sorted from lowest to highets CCN concentations. CN observations were missing on one flight nad PCASP observations above the inversion are are included

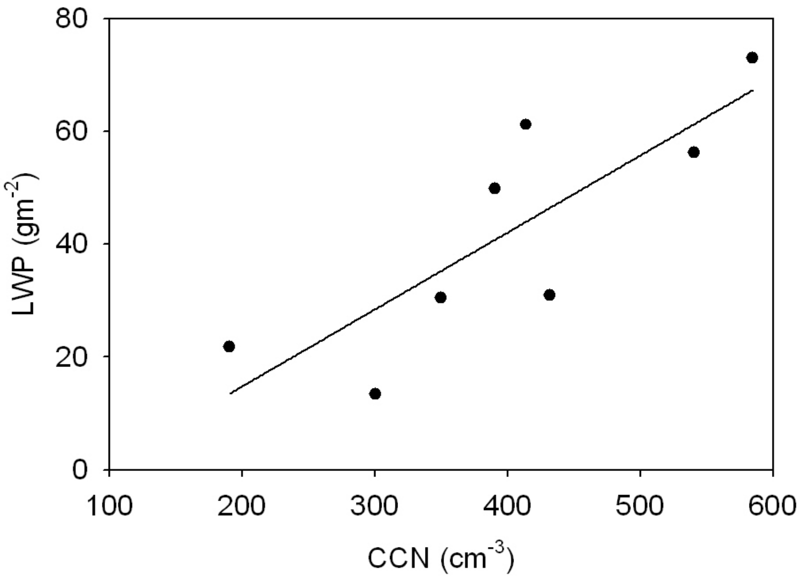

Figure 4. Cloud liquid water path (LWP) as a function of subcloud layer CCN for the eight events.

IMPACT/APPLICATIONS

The results from these studies are intended to provide an improved understanding of the physical processes associated with cloud-aerosol-drizzle-turbulence interaction that will lead the way to improved representation of the processes in models operating over a wide rang of scale and particularly for mesoscale and large-scale forecast models used in coastal and marine environments. The successful completion of the VOCALS Twin Otter observational period has already produced results that show a positive correlation in the CCN concentration in the boundary layer with the observed LWP. The variations are substantial and the reasons for these changes are being considered. The soundings that were obtained during VOCALS are being used for model evaluation of the COAMPS real-time forecast.

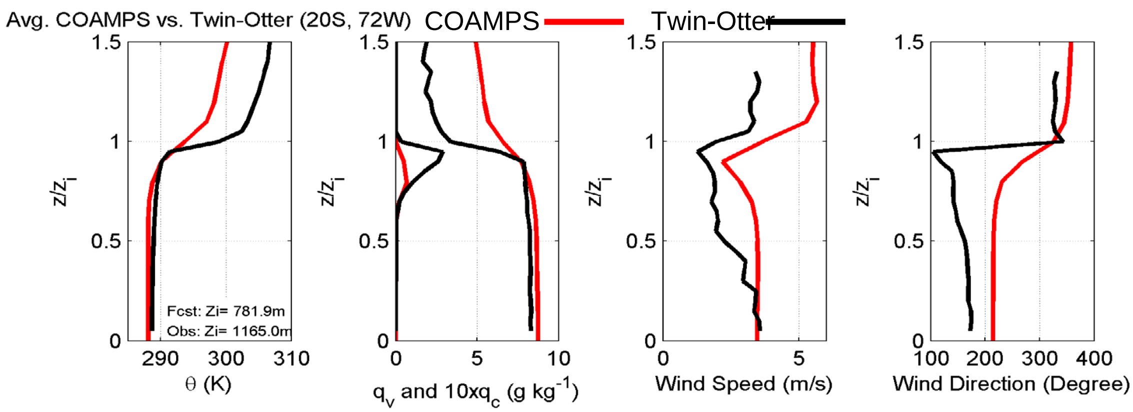

Figure 5. Evaluation of COAMPS real-time forecast using Twin-Otter soundings from VOCALS.

The NRL Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) was run by NRL scientists to provide real-time forecast for VOCALS-Rex from October 1 – November 30, 2009. One of the objectives of the real-time forecast was to comprehensively evaluate COAMPS's forecast of marine boundary layer structure. Twin-Otter research flights at "alpha point" (20S, 72W) provide excellent datasets for the COAMPS forecast evaluation. Shouping Wang at NRL at Monterey, working with the RSMAS team (Xue Zheng), compared averaged COAMPS soundings with the Twin-Otter observations (Fig. 5) where normalized thermal and wind profiles from both COAMPS and Twin-Otter are displayed. The results are follows: 1) The predicted temperature and moisture in the boundary layer are, in general, consistent with those from the observed; 2) Both COAMPS and observations show clear wind speed and directional shear across the inversion at the top of the PBL; 3) the COAMPS predicted PBL height (781 m) is considerably lower than that derived from the Twin-Otter soundings (1165 m), leading to a significantly lower cloud water mixing ratio from COAMPS; and 4) the air above the inversion from COAMPS are cooler and more moist, in part, due to the lower PBL height. Currently, NRL scientists are looking into the issue of the extremely low PBL height predicted from COAMPS near the west coast of Chile.

RELATED PROJECTS

Dr. Dean Hegg (University of Washington) is using the VOCALS Twin Otter data base to expand our knowledge of the optical properties of aerosols to construct an aerosol optical climatology for the marine atmosphere, to be used to better characterize aerosol properties in large scale models such as NAAPS. This study is examining the origin of the CCN in the cloud topped marine boundary layer, particularly with respect to the altitude of formation of such particles if formed in situ in the atmosphere but also to better characterize the fraction of MBL CCN attributable to anthropogenic and natural sources. Further, Dr. Hegg will be investigating the issue of the relative importance of size and composition on the CCN-CDNC linkage with respect to marine Sc. In general, both can be important, but at marine Sc supersaturations this may not be the case.